IMPACT OF INSTRUMENTAL DEGRADATION AND SOLAR CYCLE EFFECTS ON LONG-TERM VARIATIONS OF NLC PARTICLE SIZE RETRIEVALS WITH SCIAMACHY/ENVISAT

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ABSTRACT

SCIAMACHY limb-scatter measurements allow the continuous mapping of noctilucent clouds (NLCs) as well as the retrieval of NLC particle sizes since 2002. Long-term measurements of NLC particle sizes require high instrument stability or an accurate knowledge of the changing calibration parameters. For the NLC measurements we employ measurements in SCIAMACHY channel 1, whose transmission decreased significantly and non-linearly with time. This contribution describes the effect of instrumental degradation – if not properly corrected for – on the retrieved NLC particle sizes. Furthermore, a degradation correction scheme as well as a correction for solar cycle changes in the solar spectrum are described.

Key words: Noctilucent clouds, SCIAMACHY, Limb-scatter measurements, Instrument degradation.

1. INTRODUCTION

Noctilucent clouds (NLCs) – also known as polar mesospheric clouds (PMCs) – are a high latitude summer-time phenomenon and occur at about 82 – 85 km near the mesopause. NLCs are discussed as being early indicators of global change, because their formation and existence depends on the thermal conditions and the amount of ambient H_2O in the summer mesopause region, both of which may change as a consequence of anthropogenic activities.

Limb-scatter measurements are more sensitive to NLCs than nadir observations because of the long slant path of the line-of-sight through the atmosphere. Nearly all past and present satellite-borne limb-scatter instruments were used to study NLCs, e.g., UVS on SME, WINDII on UARS, UVISI on MSX, OSIRIS on Odin, SNOE, and SCIAMACHY on Envisat (See also Fig 1. in DeLand et al. [1]). SCIAMACHY [2] – orbiting Earth on Envisat since March 1, 2002 – is currently the only limb-scatter instrument in orbit that allows daily and global mapping of NLCs as well as the retrieval of NLC particle sizes. The particle size retrievals exploit measurements in the UV spectral range, where instrumental degradation effects are generally particularly severe.

In this contributions we discuss the impact of degradation effects in SCIAMACHY channel 1 and solar cycle variations of the solar spectrum on the NLC particle size retrievals and their long-term variations. We also present corrections for both effects.

2. NLC SIZE RETRIEVAL

The method used to retrieve NLC particle sizes has been described in detail by von Savigny and Burrows [3]. Therefore, only a brief summary is given here. The NLC spectral signature in the 265 – 300 nm spectral range (SCIAMACHY channel 1) is derived from Rayleigh-corrected limb radiance spectra using the SCIAMACHY solar irradiance spectrum of Skupin et al. [4]. The sun-normalized NLC backscatter spectra can be well approximated with by a power law $\propto \lambda^{-\alpha}$ with the Ångstrøm exponent α. The derived exponents α are then fitted with a Levenberg-Marquard scheme driving a Mie-code. The retrievals require a priori information on the NLC particle size distribution. The true NLC particle size distribution is still not fully established [5, e.g.], but recent model simulations and measurements suggest that the actual particle size distribution is better approximated by a normal – i.e. Gaussian – distribution:

$$f(r) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(r-r_0)^2}{2\sigma^2}} \tag{1}$$

than by the traditionally used log-normal distribution [6, 7]:

$$f(r) = \frac{1}{\sqrt{2\pi}r \ln \sigma} e^{-\frac{\ln^2(r/r_0)}{2\ln^2 \sigma}} \tag{2}$$

Fig. 1 illustrates the dependence of the Ångstrøm exponent on the scattering angle and the mean particle

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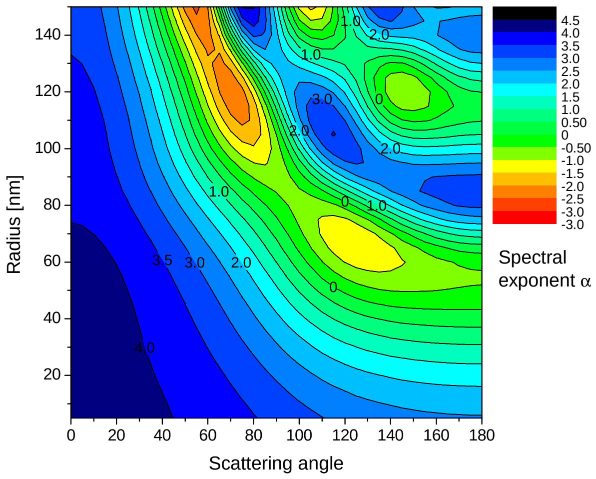

Figure 1. Modelled dependence of the Ångstrøm exponent in the 265 – 300 nm spectral range as a function of scattering angle and mean radius for a Gaussian NLC particle size distribution with σ = 16 nm.

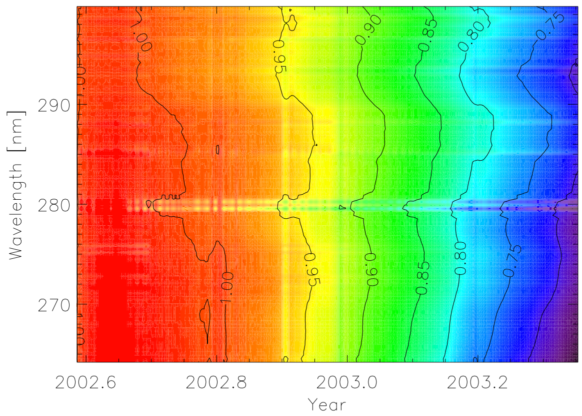

Figure 2. Degradation of transmission in the 265 – 300 nm spectral range (SCIAMACHY channel 1) as a function of time.

radius for a normal particle size distribution with σ = 16 nm. SCIAMACHY limb-scatter measurements during the northern hemisphere NLC seasons are associated with scattering angles of about 35° – 65° at polar latitudes.

The NLC spectral exponents were previously derived from SCIAMACHY limb-scatter measurements without consideration of instrumental degradation effects [3, 8]. However, degradation of the instrumental transmission is particularly severe in channel 1. Its impact on the NLC size distribution as well as a correction scheme will be discussed in the following section.

3. DEGRADATION EFFECTS

The transmission in SCIAMACHY channel 1 decreases over time, with a larger effect occurring at shorter wavelengths. Fig. 2 illustrates the temporal variation of the spectral transmission in the spectral range used for the NLC particle size retrieval. The transmission data for SCIAMACHY limb observations are provided by the SCIAMACHY Operations Support Team (SOST) and are made available on the SOST website at http://atmos.caf.dlr.de/projects/scops/. Fig. 2 shows that the transmission does not decrease linearly with time; the transmission gradient increases with time.

The effect of the transmission degradation on the determination of the sun-normalized NLC scattering spectra can be described as follows:

$$T(\lambda,t) \times \frac{I_{\mathrm{NLC}}(\lambda,t)}{I_0(\lambda)} \propto \lambda^{\gamma(t)} \times \lambda^{-\alpha} = \lambda^{-\alpha+\gamma(t)} \quad (3)$$

Here, $T(\lambda,t)$ is the spectral and temporal dependence of the transmission, $I_{\mathrm{NLC}}(\lambda,t)$ is the Rayleigh-corrected NLC limb-radiance spectrum and $I_0(\lambda)$ is the solar irradiance spectrum. In the limited spectral range used both the transmission spectra as well as the sun-normalized NLC spectra can be approximated by power laws. α is again the Ångstrøm exponent and γ is the degradation correction exponent. The transmission degradation data is used to determine the degradation correction by fitting a power law λ^{γ}. The derived exponents can directly be used to correct the NLC Ångstrøm exponents α. Note that a spectrally neutral degradation (with a degradation correction exponent of γ = 0) does not have an impact on the NLC size retrievals.

Fig. 3 shows the derived correction exponents γ as a function of time between August 2, 2002 and February 2007. For the determination of the Ångstrøm exponents the 265 – 300 nm spectral window is not used continuously, but sub-windows with airglow emissions and strong Fraunhofer-lines are neglected, as described in von Savigny and Burrows [3]. Similarly, the same spectral sub-windows are neglected for the determination of the degradation correction exponents γ. Fig. 3 shows that the degradation correction values do not vary by more than about 0.2 between 2002 and northern summer 2005 – typical values of the Ångstrøm exponents range from about 2 to 4 for NLC SCIAMACHY measurements in the northern hemisphere. However, the changes become larger after summer 2005 and the degradation correction exponent will reach a value of 1.0 in northern summer 2007.

The degradation of the solar irradiance measurements does not have to be considered, because a single SCIAMACHY solar spectrum is used.

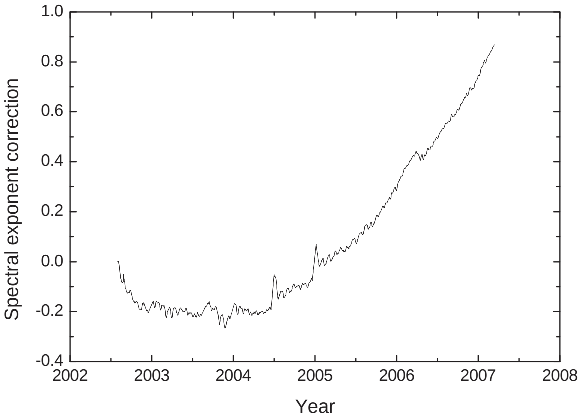

Figure 3. Ångstrøm exponent corrections derived from SCIAMACHY channel 1 transmission data.

4. SOLAR CYCLE VARIATION OF THE SOLAR SPECTRUM IN THE UV

The total solar flux exhibits solar cycle variations on the order of only 0.1%. However, the relative solar cycle changes in the UV spectral range can be significantly larger. If a constant solar irradiance spectrum is used to determine the NLC Ångstrøm exponents the solar cycle variation may lead to spurious solar cycle modulations in the retrieved NLC particle sizes. Here we quantify this effect using SOLSTICE [9] solar irradiance spectra for different solar activity on the following days during solar cycle 22: February 2, 1992, March 29, 1992, April 15, 1993, and January 2, 1995. SOLSTICE was a dedicated solar irradiance measurement instrument and is expected to provide more accurate solar irradiance spectra and better long-term stability than SCIAMACHY.

In order to determine the effect of a changing solar spectrum on the derived Ångstrøm exponents we use ratios of the SOLSTICE spectra for the different days. These ratios can be well approximated by power law functions $\lambda^{-\delta}$ with exponents δ. The exponents can then be related to the MgII-index, which is available from SBUV, SUSIM, GOME and SCIAMACHY measurements on a daily basis starting in 1978 [10, e.g.]. The MgII index is essentially the core-to-wing ratio of the solar irradiance of the Mg-Fraunhofer line at 280 nm [10] and is a well established solar activity proxy. Fig. 4 shows the relationship between the solar cycle correction exponents and the MgII indices for the corresponding day referenced to August 22, 2002, when the SCIAMACHY solar irradiance spectrum used in this study was measured. The MgII-index on August 22, 2002 was 0.14653. Obviously there exists a very good linear relationship between the two quantities, justifying the use of daily MgII index values together with a linear approximation of the data in Fig. 4 to determine a correction coefficient for the NLC Ångstrøm exponents on a daily basis.

Fig. 5 shows the MgII index time series between January 2002 and December 2007 as well as the derived spectral exponent corrections based on the linear fit shown in Fig. 3. Between northern summers 2002 and 2006 the spectral exponent correction δ changes by about 0.04, which is significantly smaller than the effect of instrumental degradation discussed in section 3.

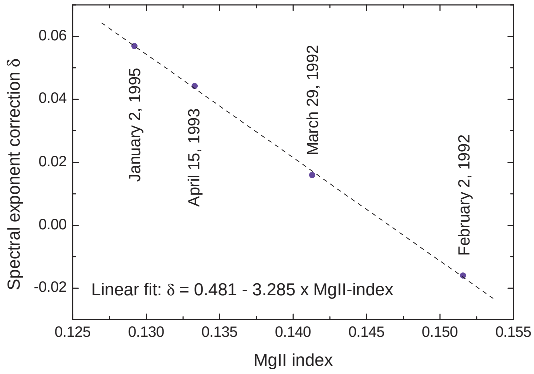

Figure 4. Ångstrøm exponent correction for solar cycle variations of the shape of the solar irradiance spectrum as a function of the MgII index. The correction exponents are referenced to the MgII index for August 22, 2002, the day when the SCIAMACHY solar irradiance spectrum used for the NLC particle size retrieval was measured.

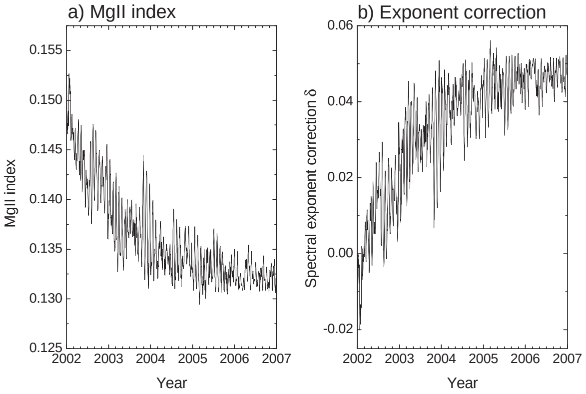

Figure 5. Left panel: MgII-index for the period January 2002 – December 2006. Right panel: Temporal variation of the correction exponent derived from the linear fit shown in Fig. 4. The strong variations in the MgII index and the exponent correction in late 2003 are associated with the October/November 2003 solar proton event.

5. IMPACT OF DEGRADATION AND SOLAR CYCLE VARIATIONS ON RETRIEVED NLC PARTICLE SIZES

In this section we estimate how the instrumental degradation as well as the solar cycle variation of the shape of the solar spectrum affect the Ångstrøm exponents and the derived NLC particle sizes. We estimate the errors in the retrieved NLC particle radii – for a Gaussian particle size

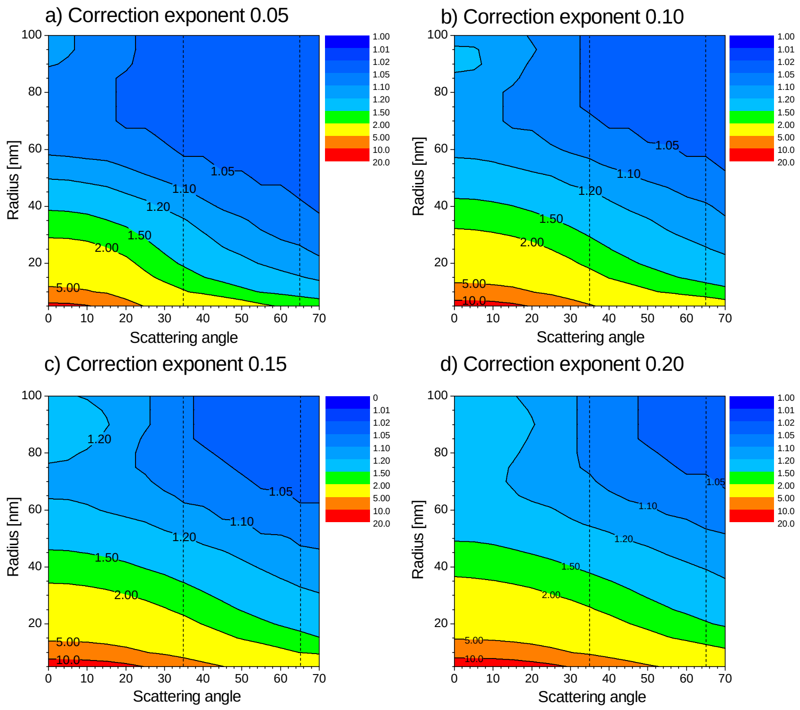

Figure 6. Relative impact of different spectral exponent corrections on the retrieved radii for the range of scattering angles (indicated by the dashed lines) typical of SCIAMACHY limb observations at high polar latitude during northern summer. The values were derived for a normal NLC particle size distribution with σ = 16 nm. Note that the correction exponents were subtracted from the Ångstrøm exponents.

distribution with σ = 16 nm – if the Ångstrøm exponents are reduced by values of 0.05, 0.1, 0.15 and 0.2. Decreasing Ångstrøm exponents lead to increasing particle sizes. Fig. 6 shows the ratio between the changed and the original radii as a function of scattering angle and radius. Apparently the impact of Ångstrøm exponent errors depends on the scattering angle – this is also evident in Fig. 1 from the different dependence of the exponents on the radii for different scattering angles – and the error decreases with increasing scattering angle. Moreover, the radius retrieval error decreases with increasing particle size. For an error in the Ångstrøm exponent of 0.05 (panel a in Fig. 6) the radius retrieval errors range from about 5% – 20% for a mean radius of 40 nm and the typical range of scattering angles of SCIAMACHY limb measurements during northern NLC seasons at polar latitudes. An exponent error of 0.05 roughly corresponds to the maximum effect associated with the solar cycle variability of the solar spectrum in the UV spectral range used for the NLC particle size retrievals – as discussed in section 4. If the spectral exponent errors reach 0.2 (panel d in Fig. 6) – which is well possible if the transmission degradation discussed in section 3 is neglected – then the radius retrieval errors vary between about 20% and 50% for a mean radius of 40 nm and the typical range of scattering angles.

Both effects – degradation and solar cycle variations – vary slowly with time and may introduce spurious long-term and/or solar-cycle variations, and need to be considered for an accurate retrieval of long-term trends in NLC particle sizes. An interesting question is whether the expected solar cycle variation in NLC radii can in principle be retrieved. If we assume that (a) the NLC ”brightness” or albedo exhibits a solar cycle change on the order of 20% – as seen in the SBUV measurements [1, e.g.] – and (b) the brightness roughly scales with the 5th power of the NLC radius, then the corresponding solar cycle variation in the mean NLC radii is less than 4%. This is certainly a simple estimate based on crude assumptions, but nevertheless allows the conclusion that only small solar cycle changes in the NLC radii can be expected. Solar cycle variations of the NLC particle radii on the order of a few percent are probably very difficult to detect.

6. CONCLUSIONS

The impact of instrumental degradation in SCIAMACHY channel 1 as well as solar cycle variations in the solar irradiance spectrum in the UV spectral range on NLC particle size retrievals were quantified. Particularly the instrumental degradation has a significant effect on the NLC particle sizes – on the order of 50% and more between 2002 and 2006 and needs to be corrected for. In comparison, the effect of solar cycle variations in the solar irradiance spectrum are rather small. An empirical correction of the degradation effect based on daily channel 1 transmission spectra is proposed and will be applied to future retrievals. The solar cycle variation can be corrected using the MgII solar activity proxy together with highly accurate solar UV irradiance spectra measured with SOLSTICE on UARS. A multi-year climatology of NLC particle sizes and NLC occurrence based on SCIAMACHY limb measurements will be presented in a forthcoming publication [11].

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